



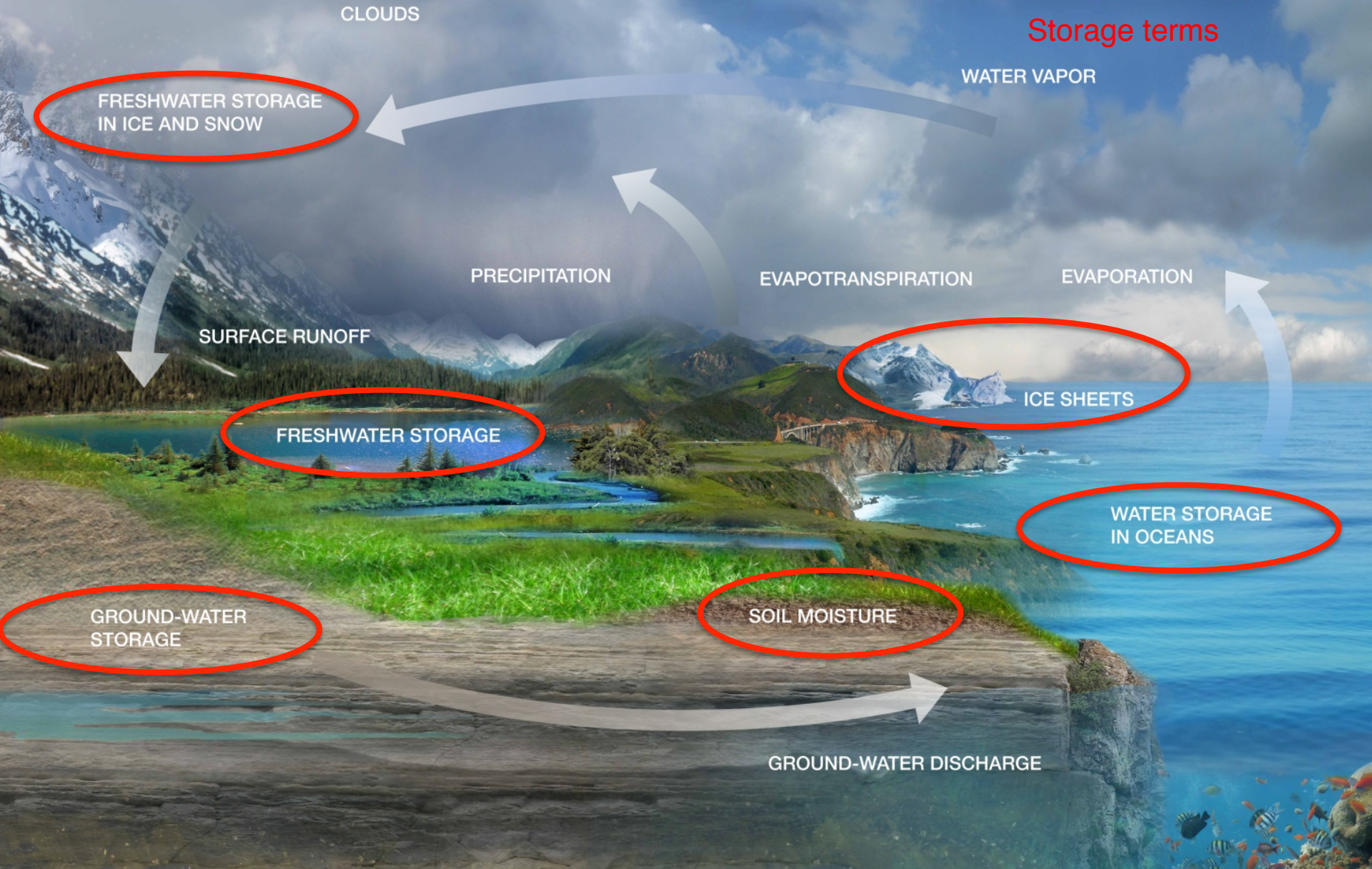
Gravity and the Water Cycle: 15 years of GRACE observations

Carmen Boening
GRACE Project Scientist

Jet Propulsion Laboratory, California Institute of Technology

WATER CYCLE

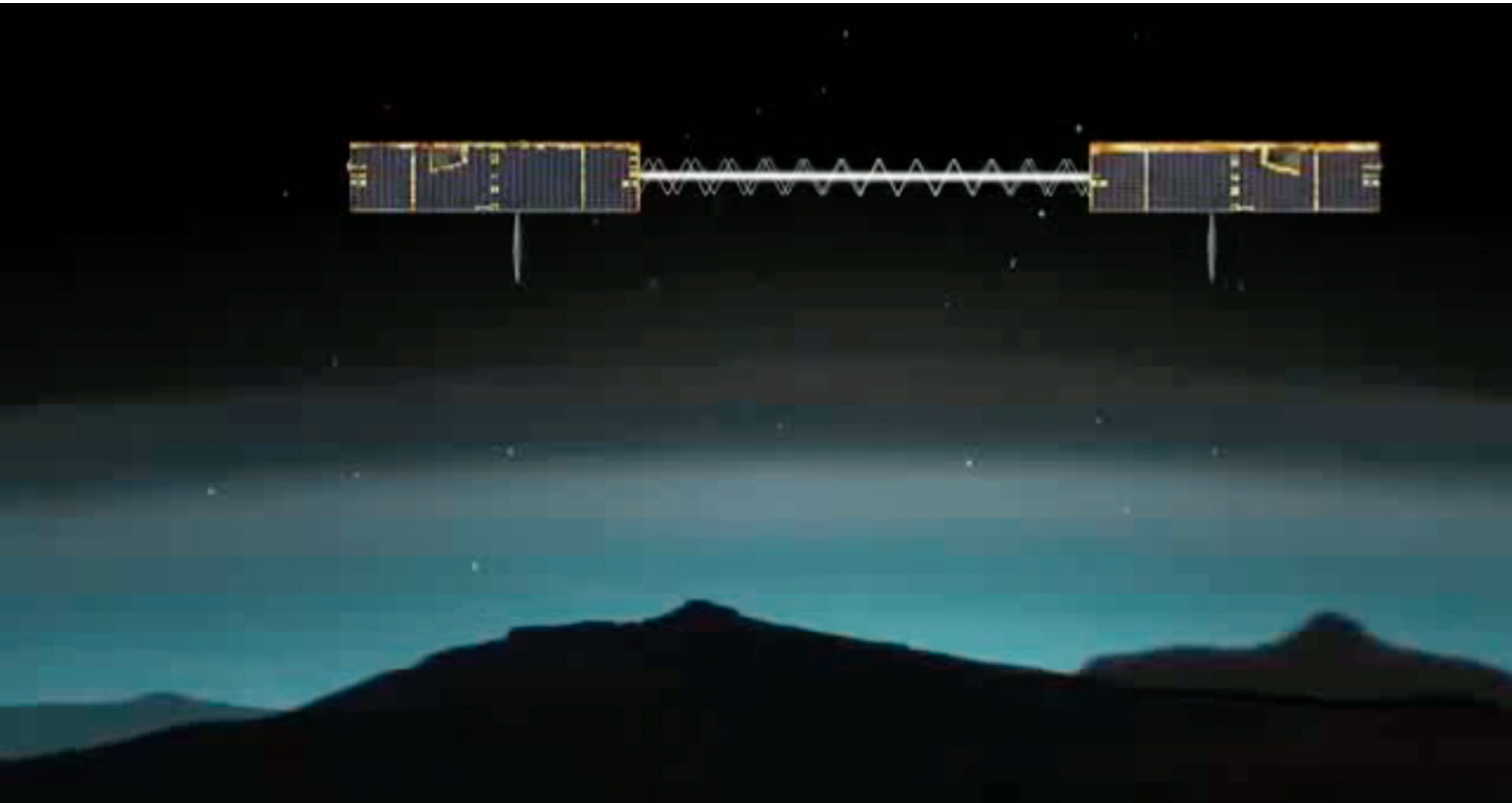
Storage terms



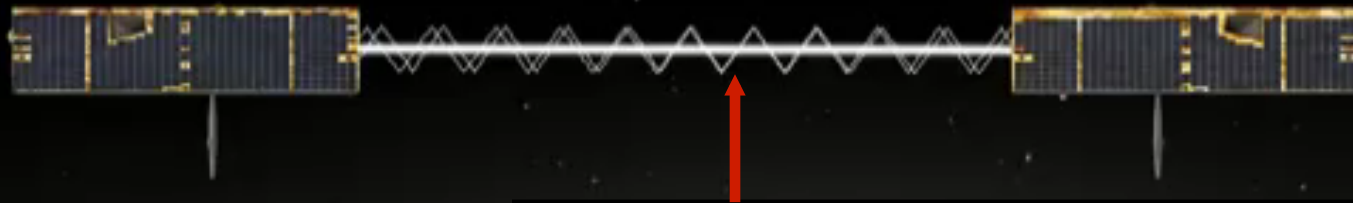
Gravity Recovery and Climate Experiment



GRACE Measurement



GRACE Measurement



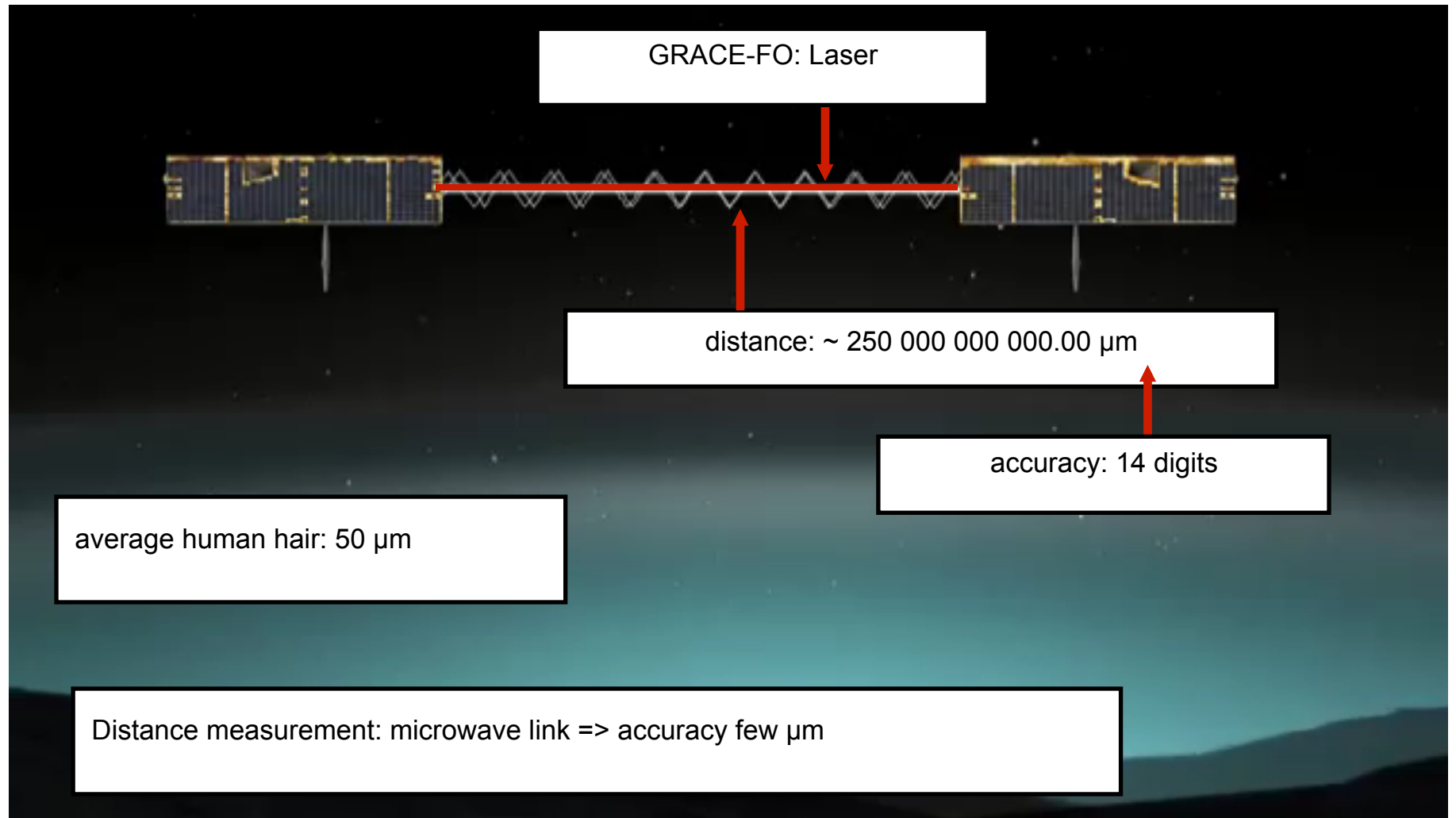
distance: $\sim 250\,000\,000\,000\,\mu\text{m}$

accuracy: 12 digits

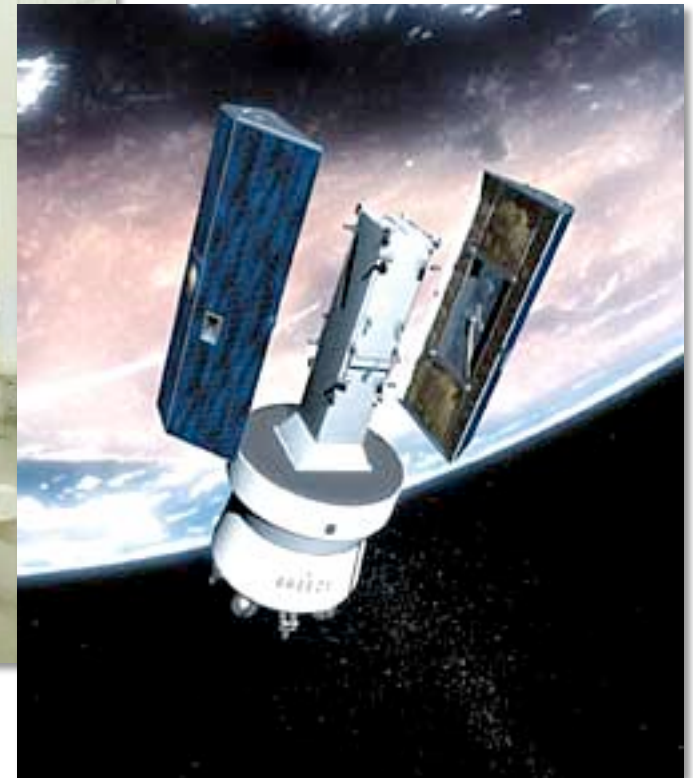
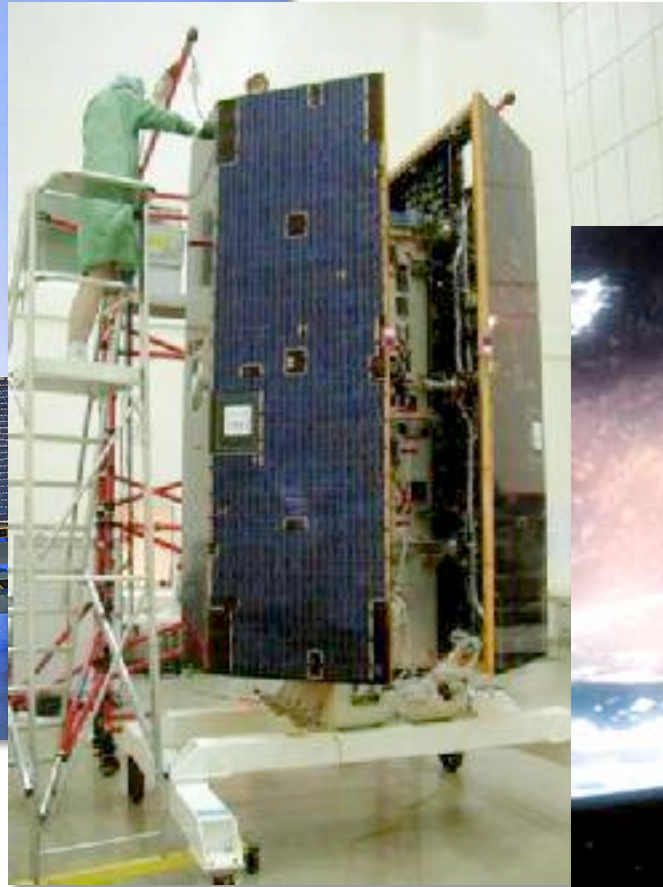
average human hair: $50\,\mu\text{m}$

Distance measurement: microwave link \Rightarrow accuracy few μm

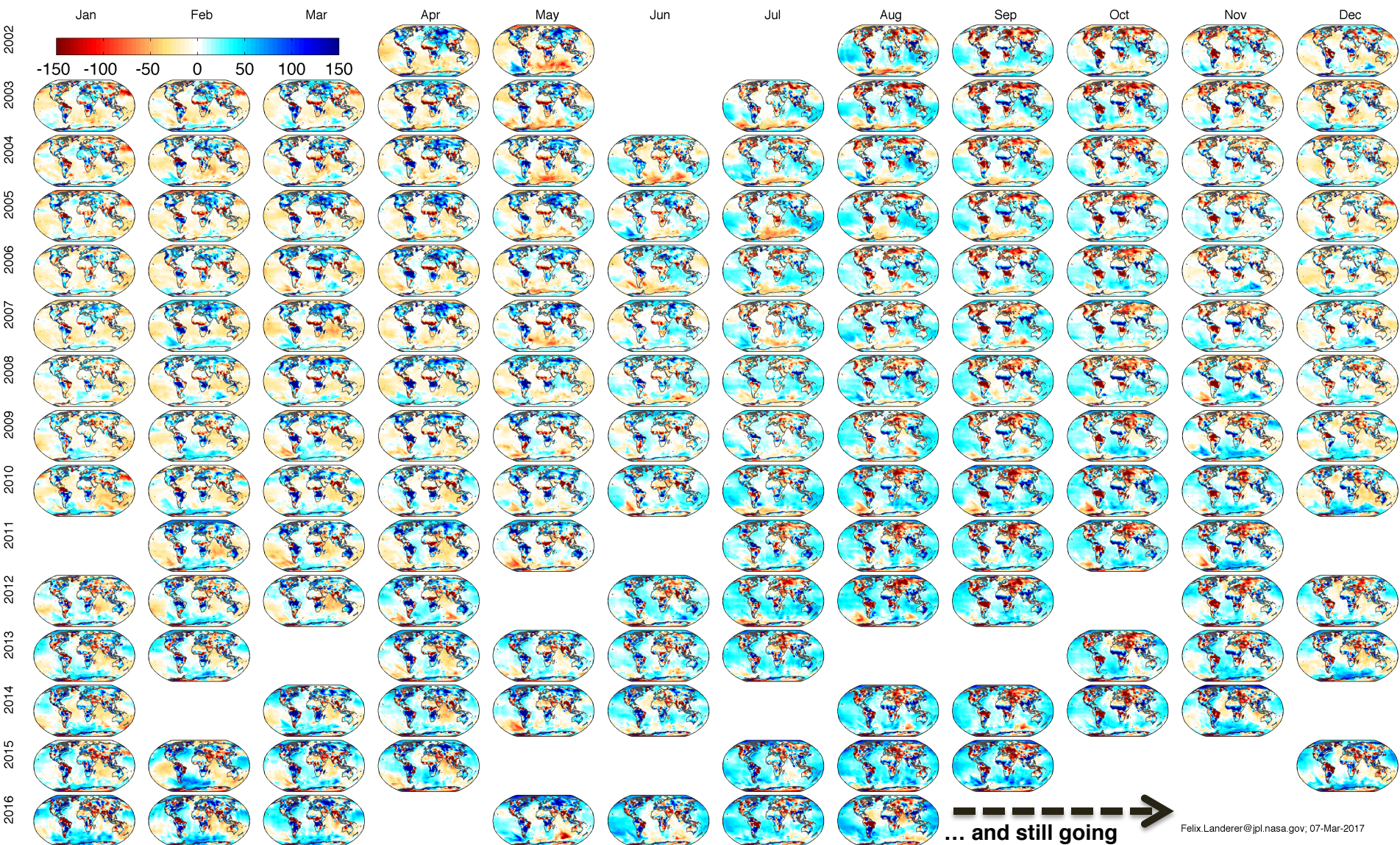
GRACE & GRACE-FO



GRACE Satellites in 2002



March-2016: Happy (15th) Birthday!



Mission Status

Launched: March 17, 2002

Nominal mission: 5 years

14.99 years in orbit (5472 days)

Initial altitude: 485 km

Current altitude: ~336.4 km (-88 m/d)

Operations Challenge: Operate until 2018

2015 NASA Senior Review identified an overlap with GRACE-FO mission as a high priority objective

Mission Lifetime Issues

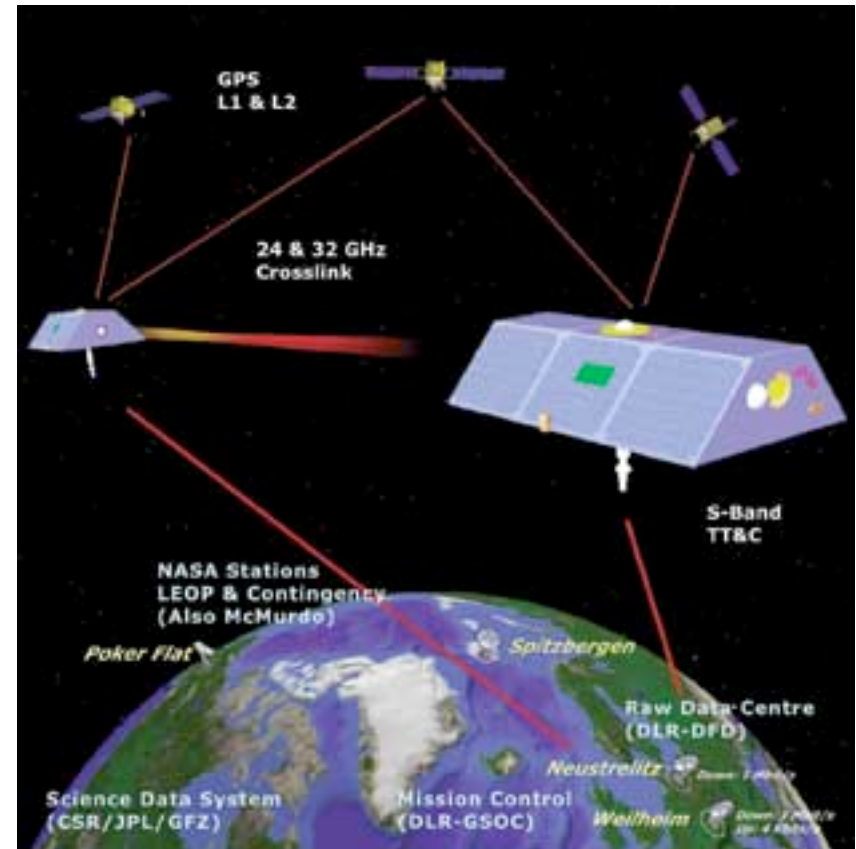
Altitude Decay: Drag estimates predict lifetime to last at least through 2017

Battery Capacity: Uncertain, but current strategy *might* allow operation until 2018.

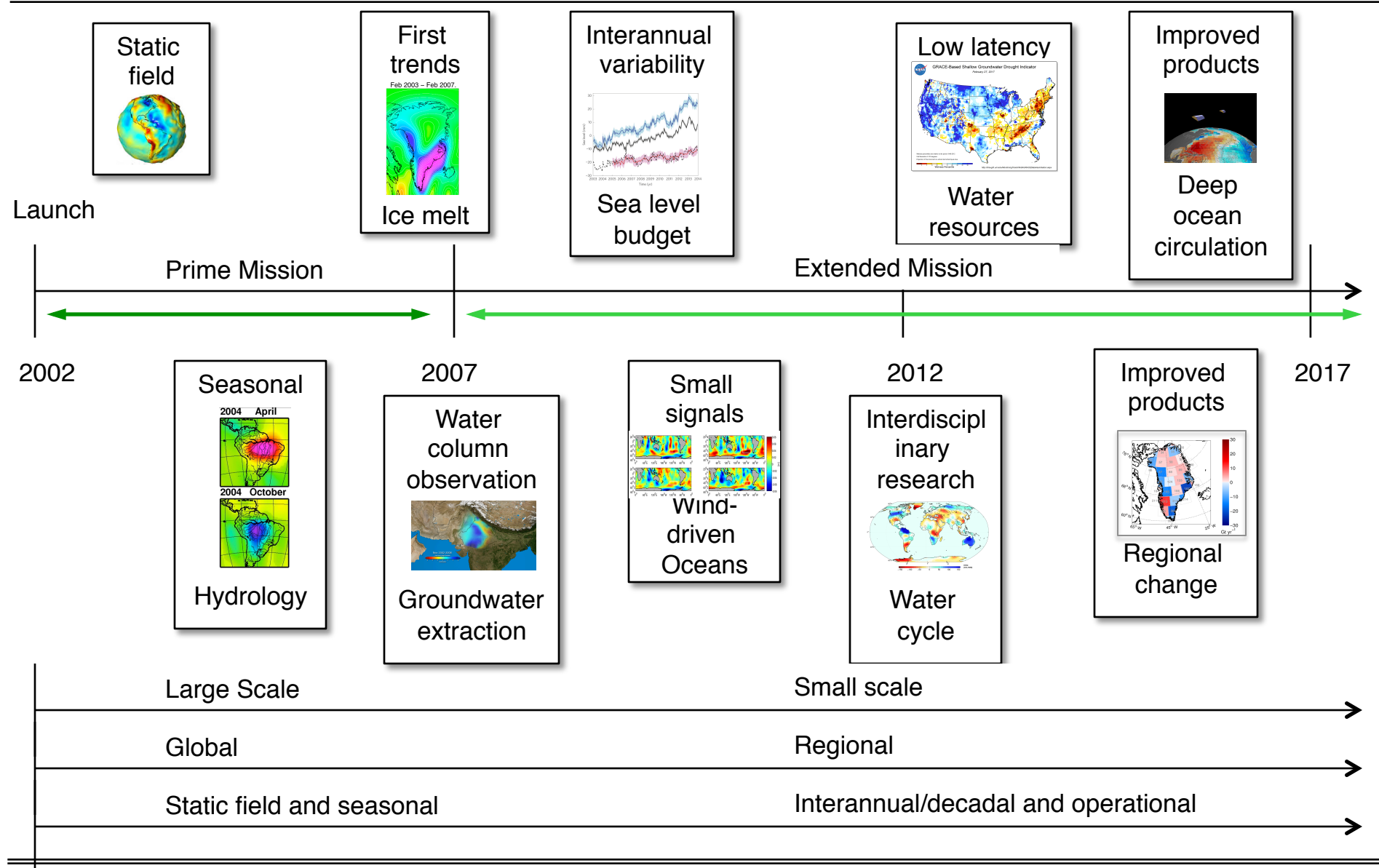
Propellant for Attitude Control: Available until end of 2017

Single String Instrument Operations:

Degraded science mission options under study

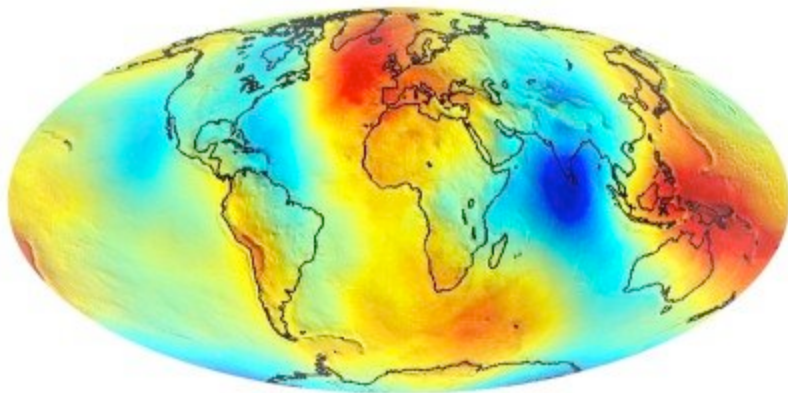


A history of discoveries

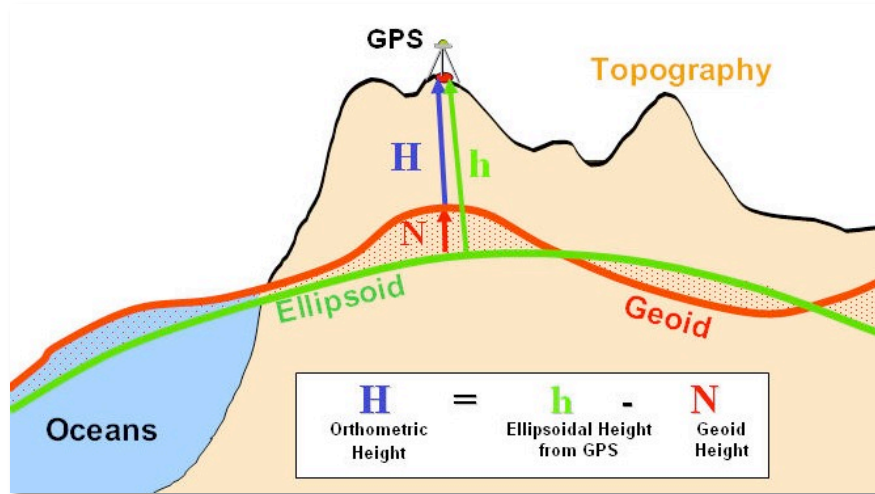
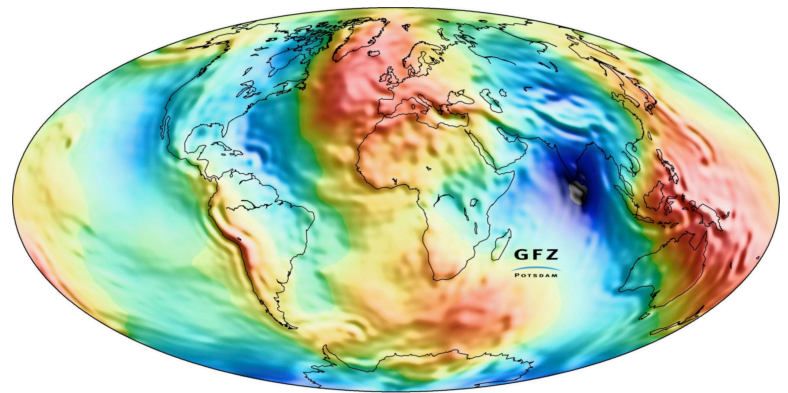


Geoid – The Static Gravity Field

Then ...



... Now

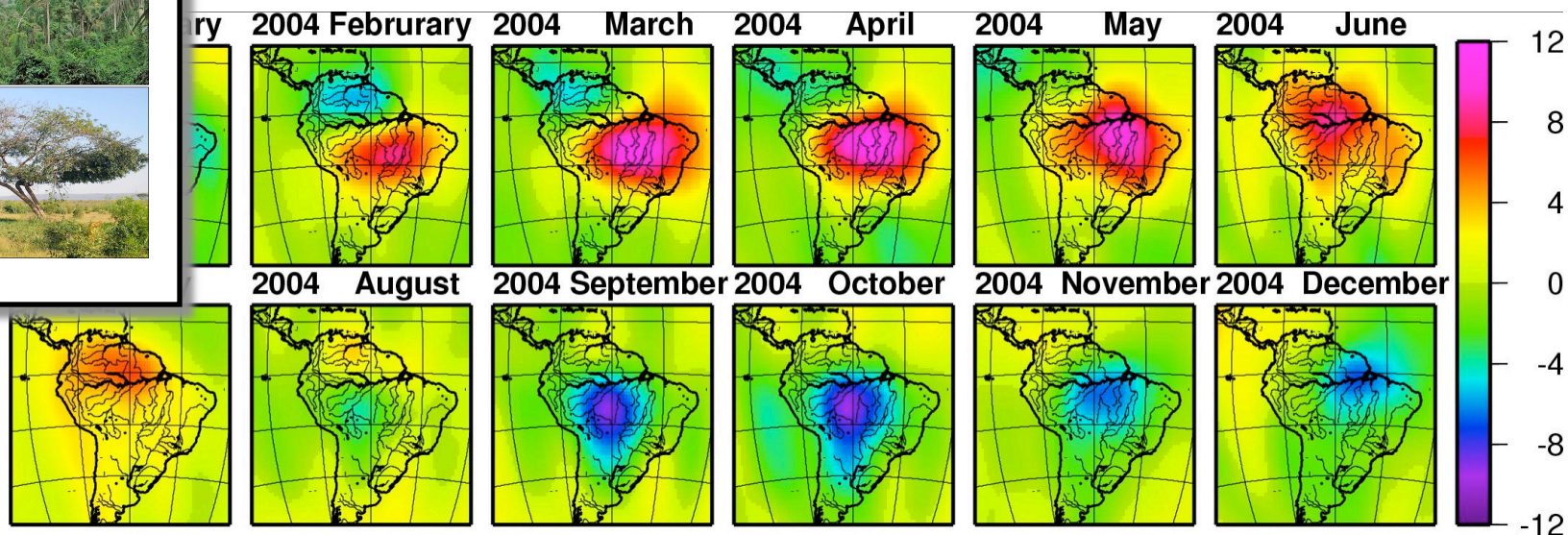


Geoid important reference surface, particularly for ocean applications

Two orders of magnitude improvement compared to pre-GRACE

Observing seasonal variability in land hydrology

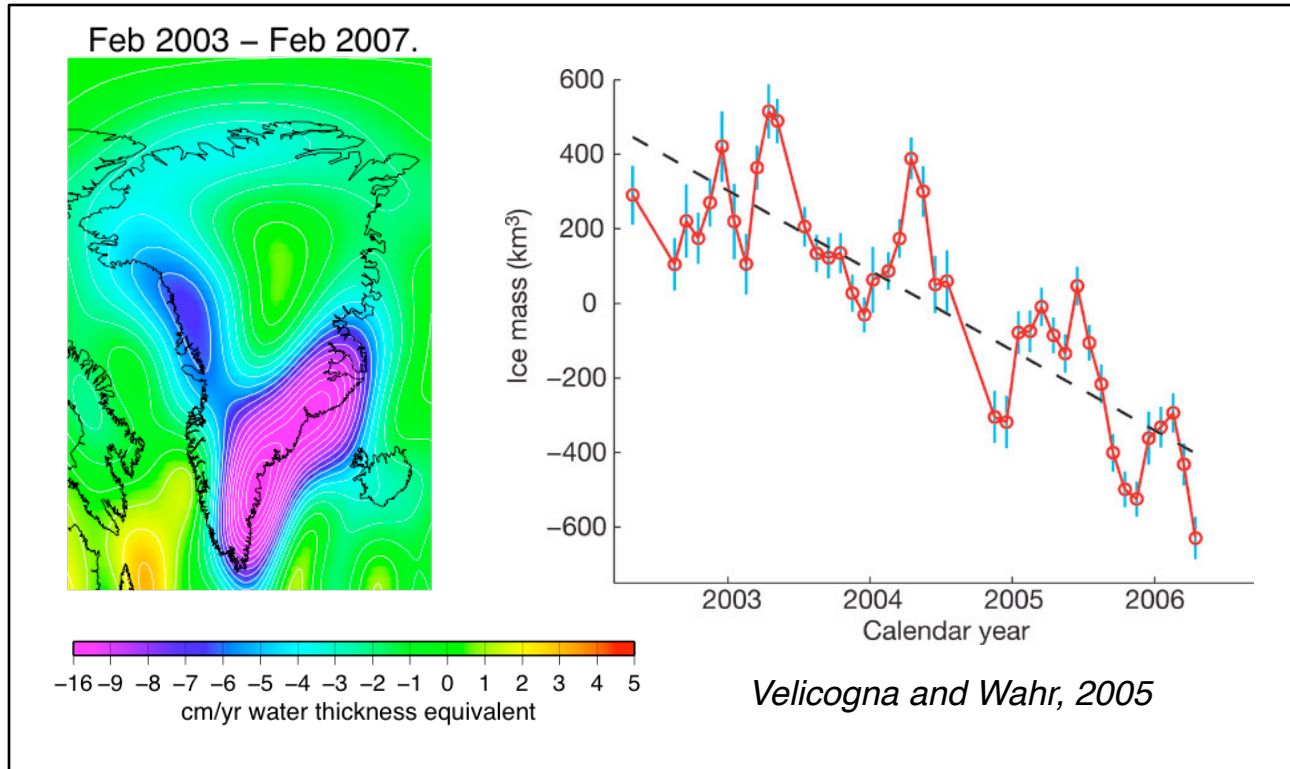
Hydrologic variability



GRACE helps to characterize the rainy and dry season over major hydrologic basins

Chen et al., 2005

First big signals in the time-varying gravity field: Greenland mass loss

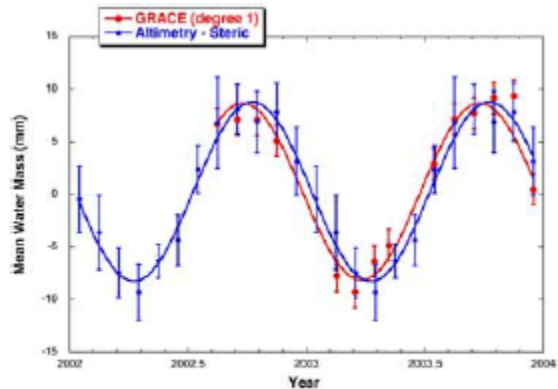


GRACE allows for a first look at Greenland ice loss

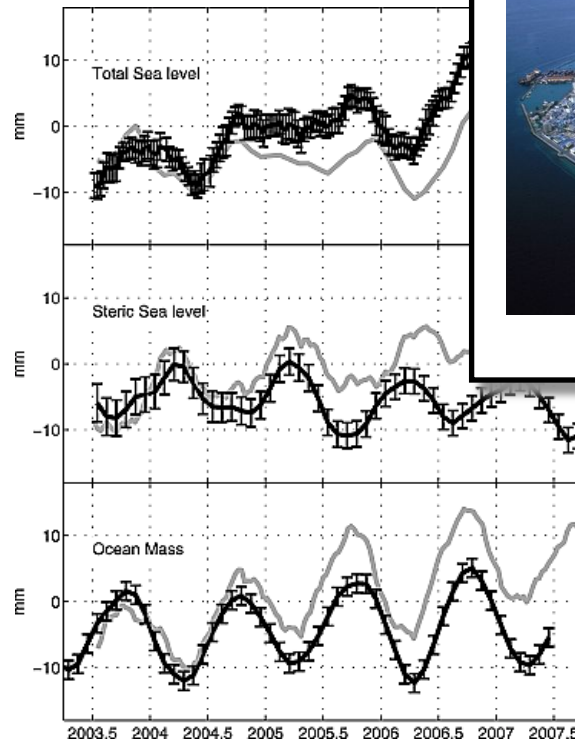
- First quantitative measurement
- Characterization of seasonal cycle

From big signals over land to small signals over the ocean

*From seasonal to interannual:
Sea level budget on different time
scales*



Chambers and Wahr, 2005



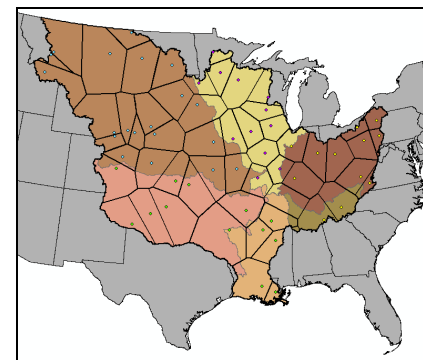
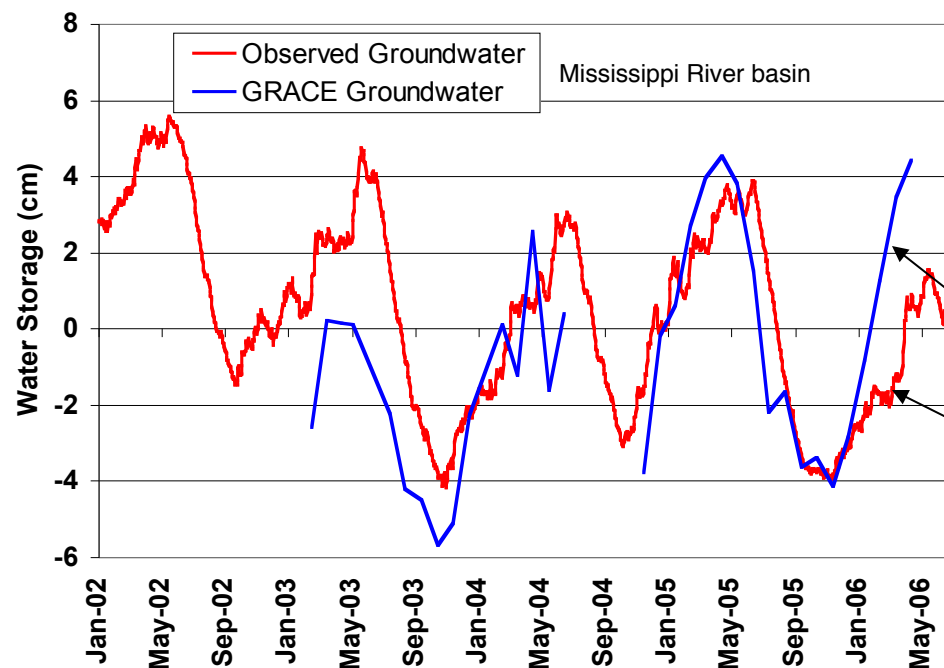
Willis and Chambers, 2008

Sea level



*First combinations with complementary satellite and
in-situ data*

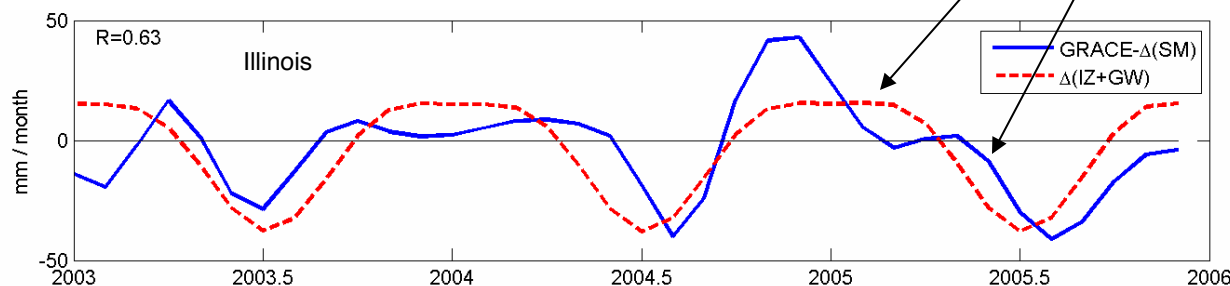
GRACE Is the First Satellite to Monitor Groundwater Levels



GRACE groundwater estimate

Groundwater well observations

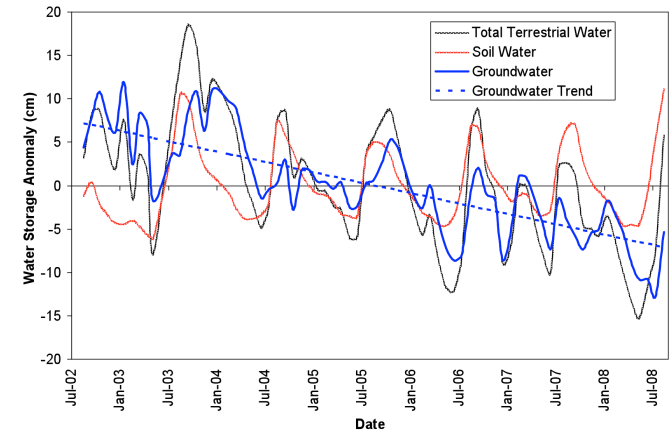
GRACE groundwater estimates (smoothed)



GRACE: Tracking Earth's Groundwater



Groundwater depletion in NW India



Rodell et al., 2009

*GRACE reveals groundwater depletion
due to irrigation*

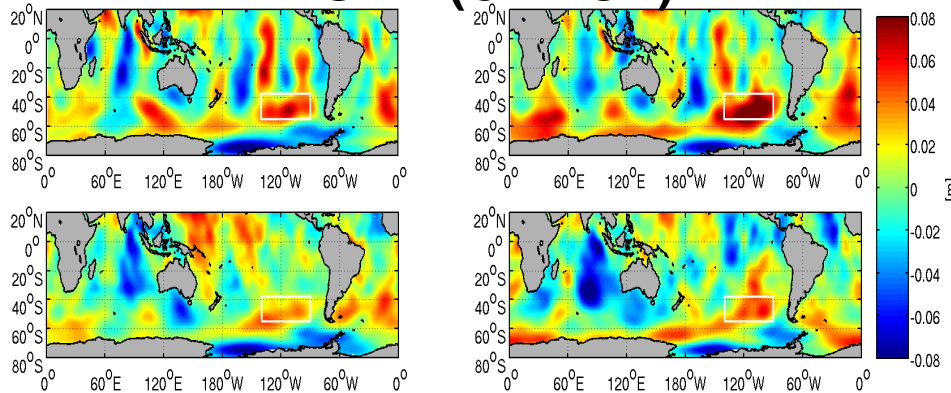
*Water storage changes not visible at
the surface but visible in gravity*

Irrigation

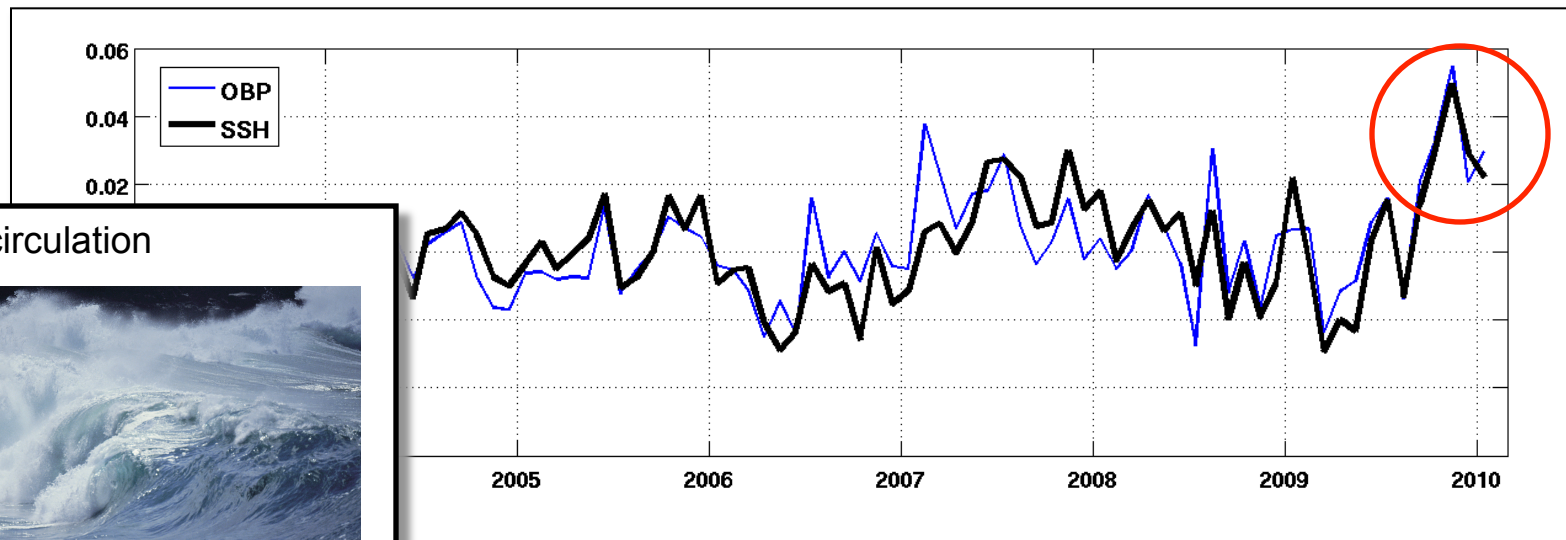
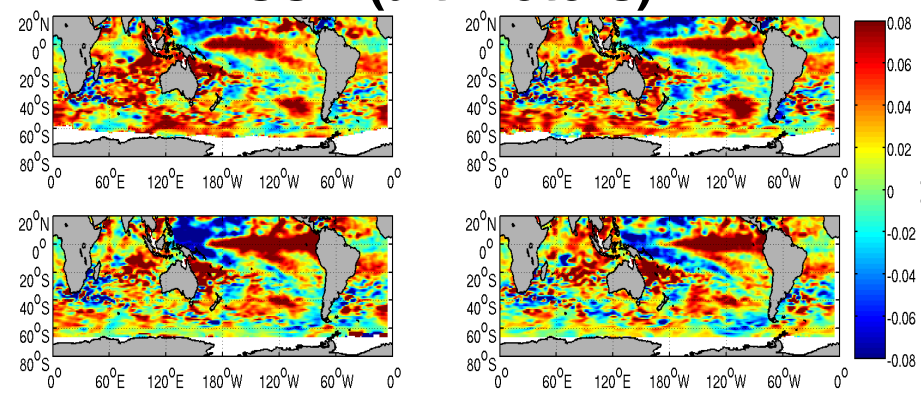


From big signals to small – GRACE for understanding ocean circulation

OBP (GRACE)



SSH (altimeters)

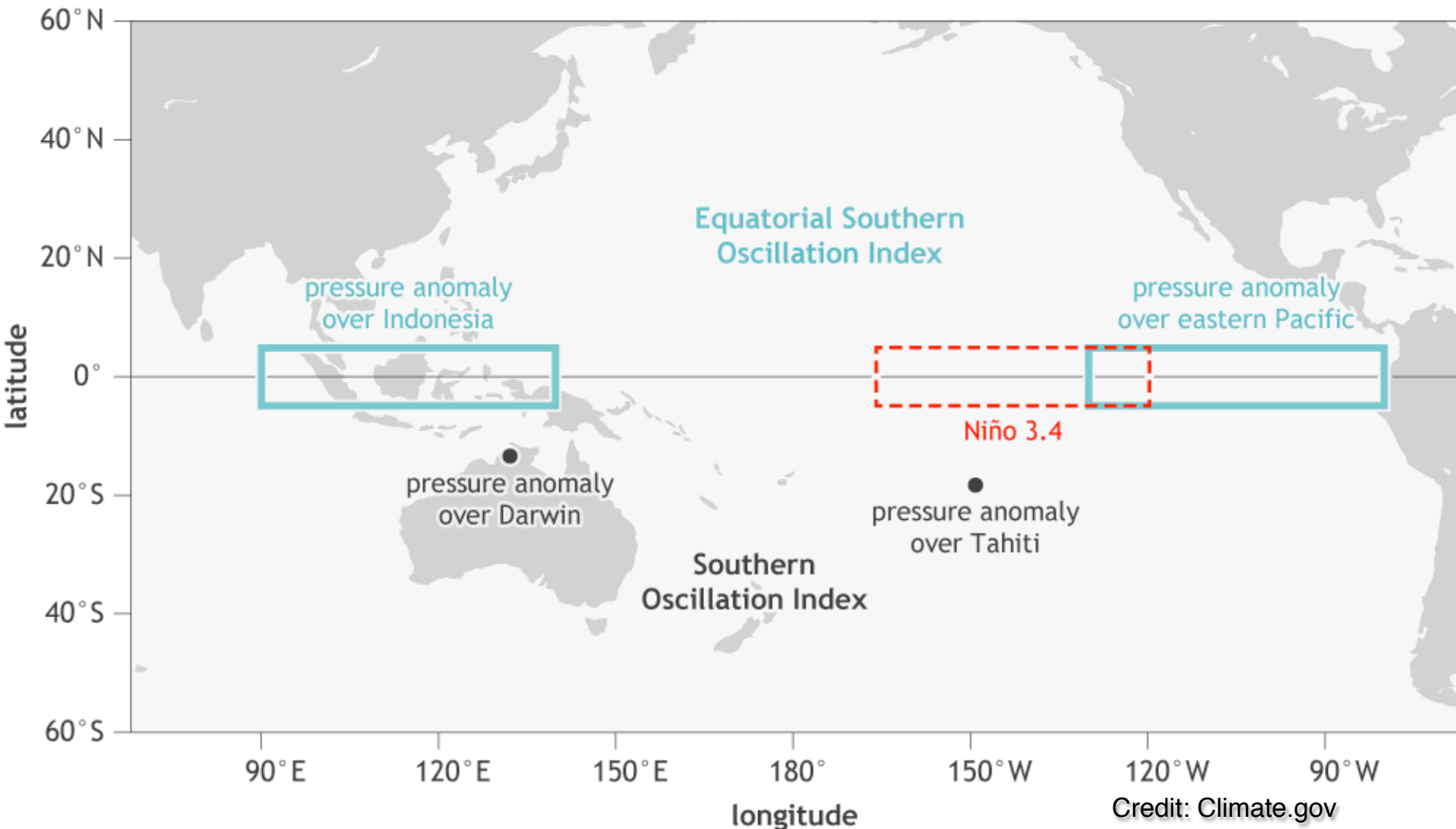


Ocean circulation



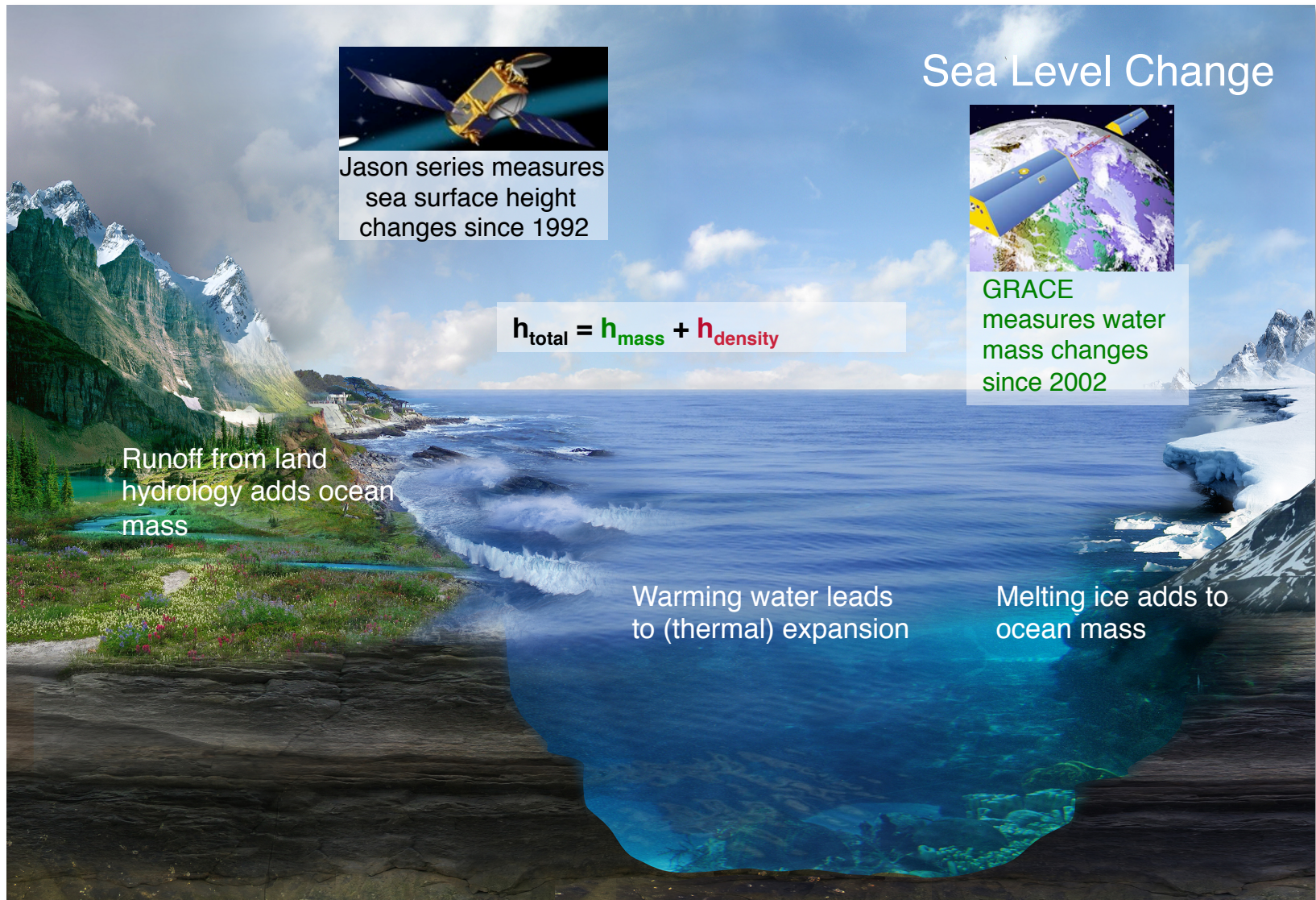
Long-term vs. short-term variability – ENSO and the water cycle

ENSO indexes

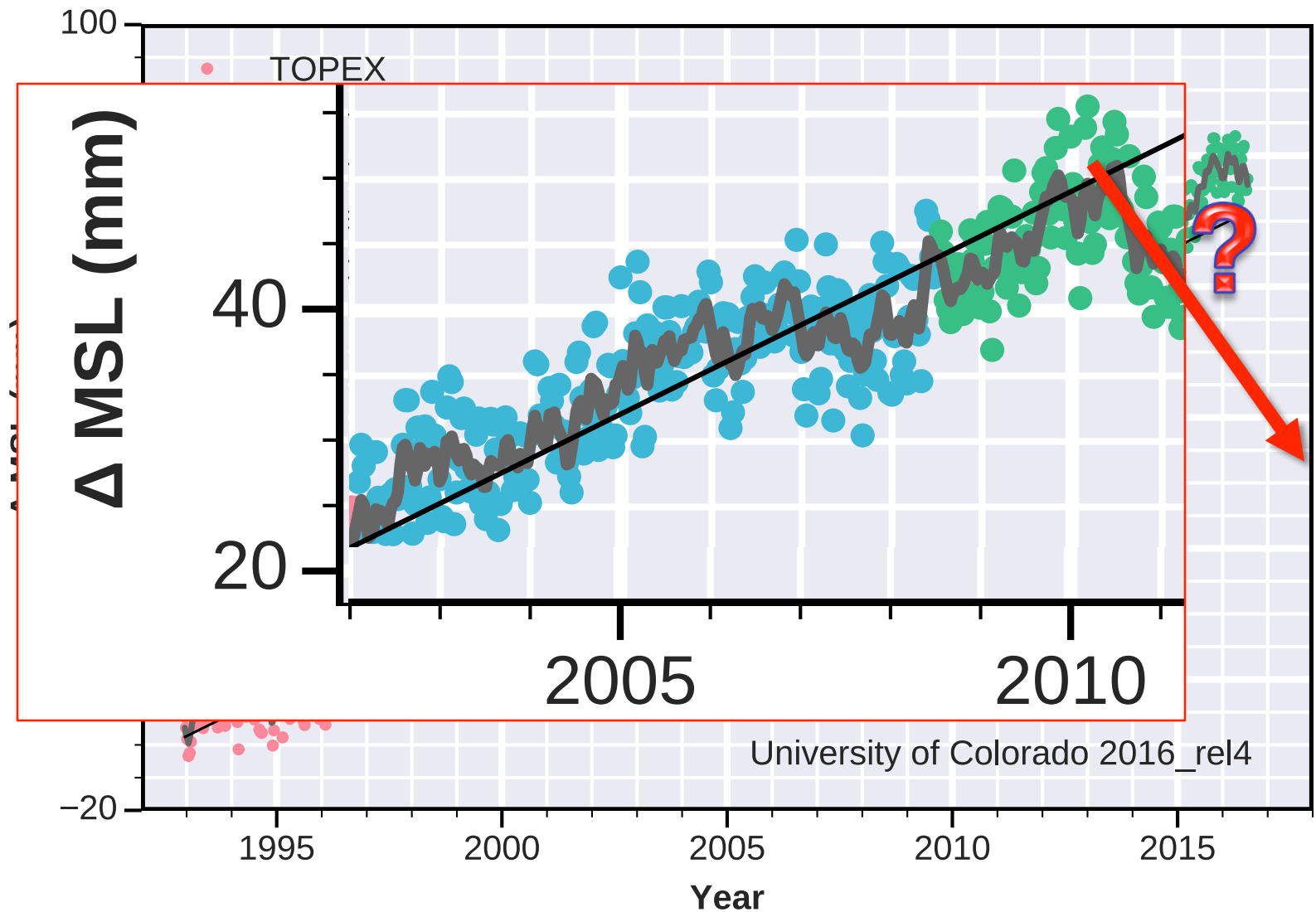




Causes and Observations of Sea Level Change

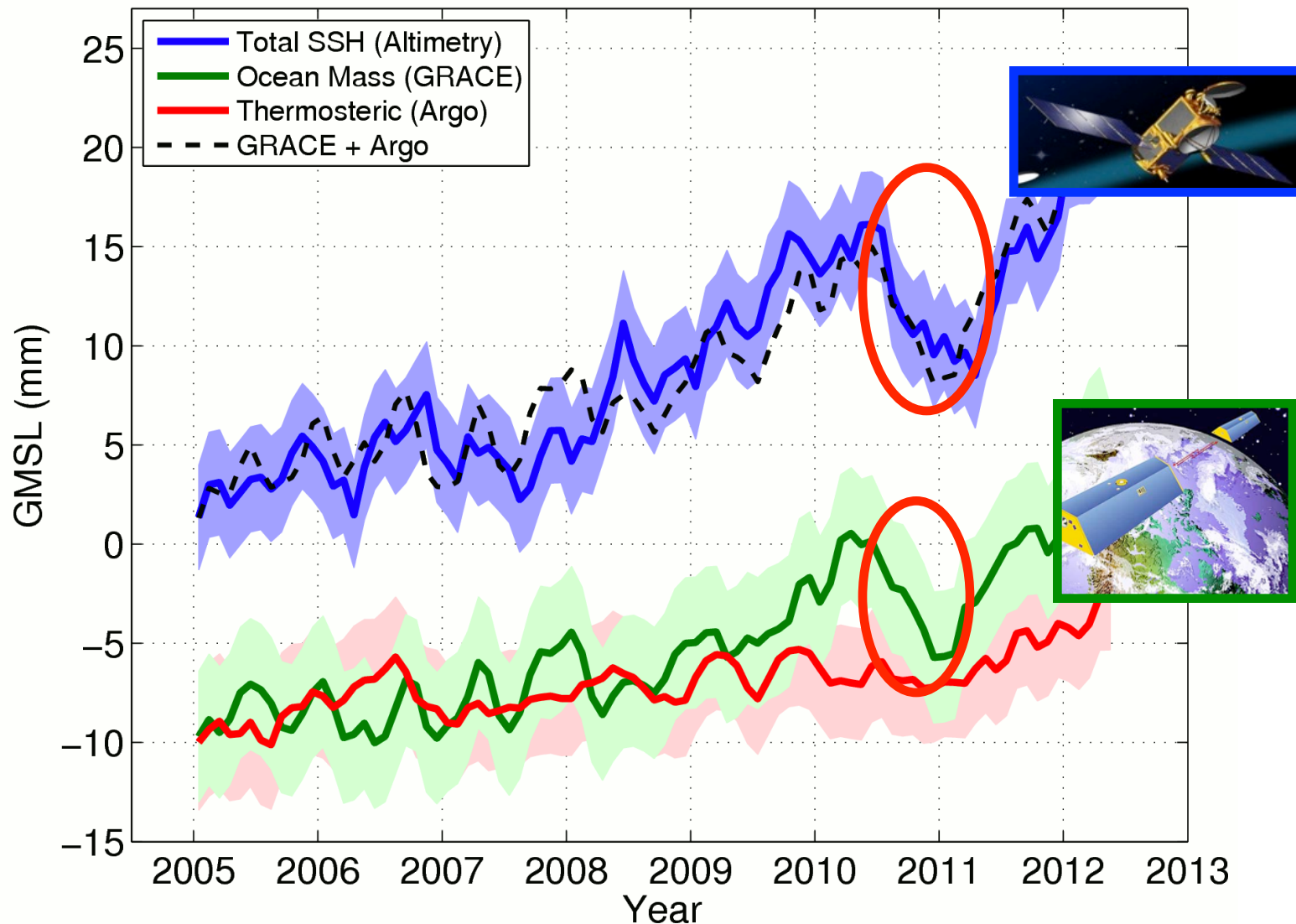


Records of sea level change since 1992





Using Multiple Satellites to “Track” Water



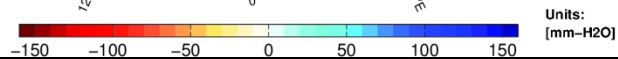
Terrestrial Water Storage in 2010 and 2011

GRACE finds sea level change and water storage are intimately linked

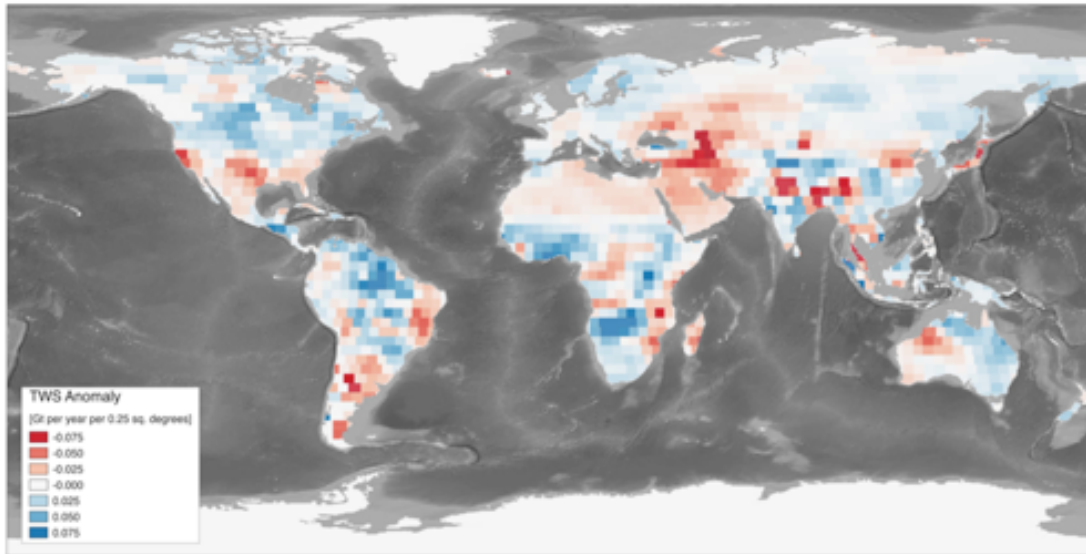
Global view of the water cycle
Short term vs long term change

water accumulates in Australia's Warburton Creek in late 2010

GRACE water storage data from 2010 indicates more water in Australia and South America.

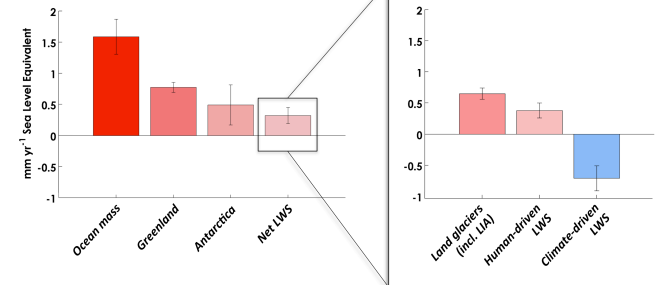


Sea Level Rise Slowed by Climate-Driven Hydrology



Reager et al., 2016

Sea level and hydrology



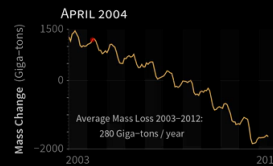
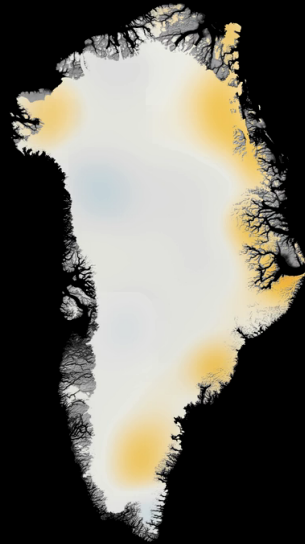
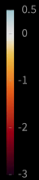
Importance of decadal change in hydrology:

GRACE helps to re-assess sea level trends

Ice Sheet Loss affecting sea level

GREENLAND ICE MASS LOSS
2003-2013

Change in ice mass since 2003
equivalent water height (meters)

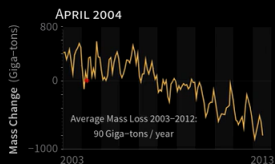
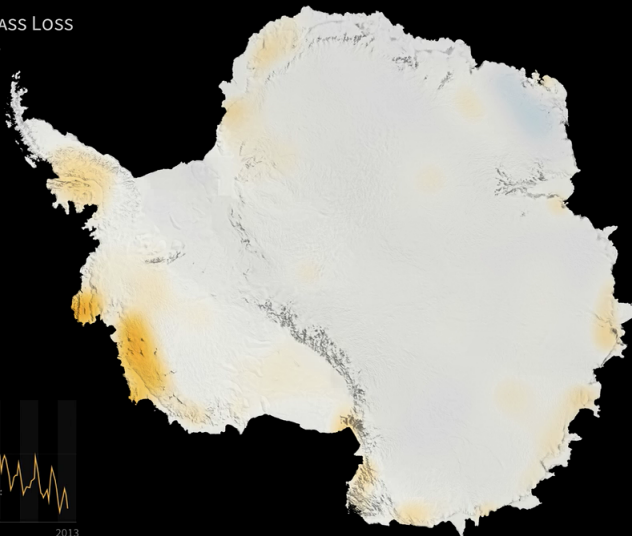
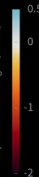


**Greenland: ~7 m sea level eqv.
Antarctica: ~60 m sea level eqv.**

***GRACE weighs the ice sheets
and identifies loss and gain on
regional level***

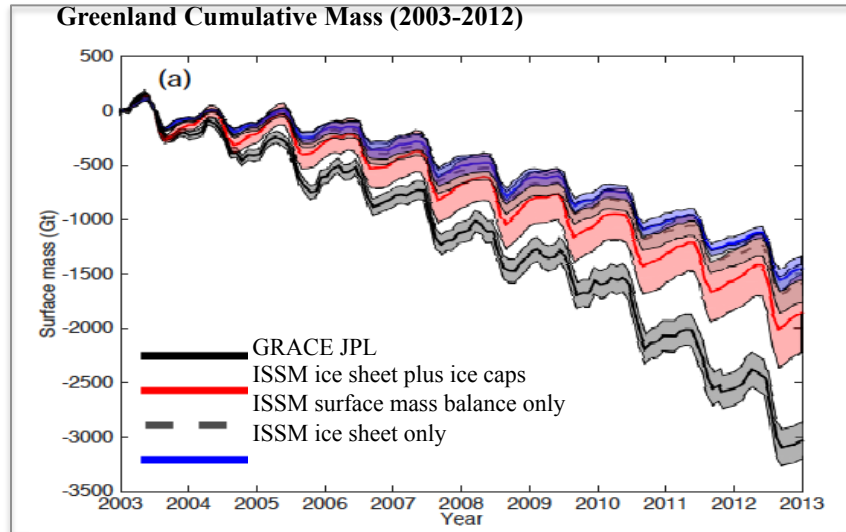
ANTARCTIC ICE MASS LOSS
2003-2013

Change in ice mass since 2003
equivalent water height (meters)

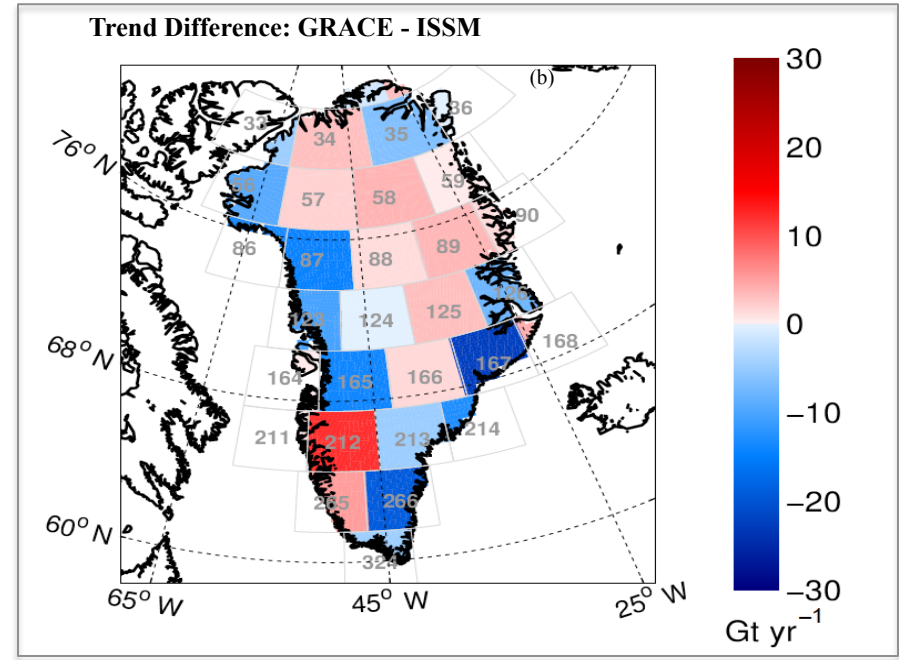


**Continuous measurements
ensure we identify regional
change and long term vs short
term variations which ensures
an “early warning system”**

Utility of GRACE in assessing model estimates of Greenland mass change

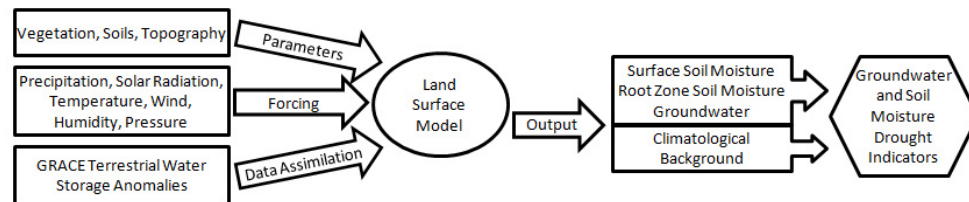


Schlegel et al., 2016



Identifying processes behind ice mass loss by combining GRACE data with ISSM model output - Surface mass balance vs. discharge

GRACE for operational use: National Drought Monitor



GRACE-Based Surface Soil Moisture Drought Indicator

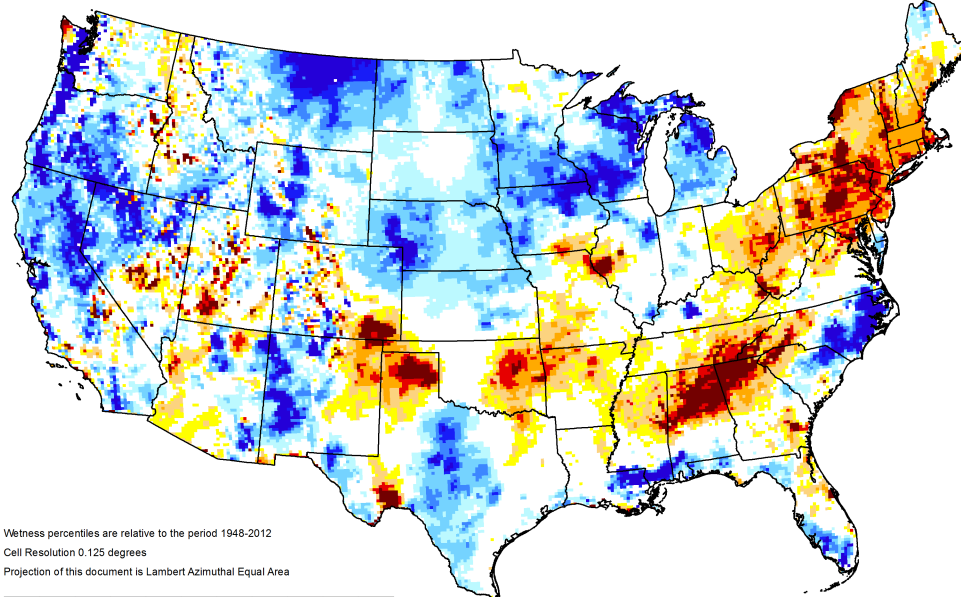


GRACE-Based Root Zone Soil Moisture Drought Indicator

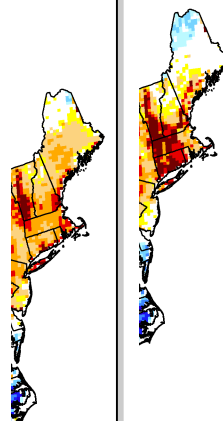


GRACE-Based Shallow Groundwater Drought Indicator

January 16, 2017



<http://drought.unl.edu/MonitoringTools/NASAGRACEDataAssimilation.aspx>



lation.aspx

lation.aspx

Weekly GRACE data assimilation for Soil Moisture and Groundwater Drought Indicators

Integral water storage provides insights into below-surface water reservoirs



National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

California drought

**GRACE captures
duration and intensity of
droughts**

*Continuous
measurements identify
groundwater loss vs.
surface storage*

Gravity for early warning?

Saturated soils



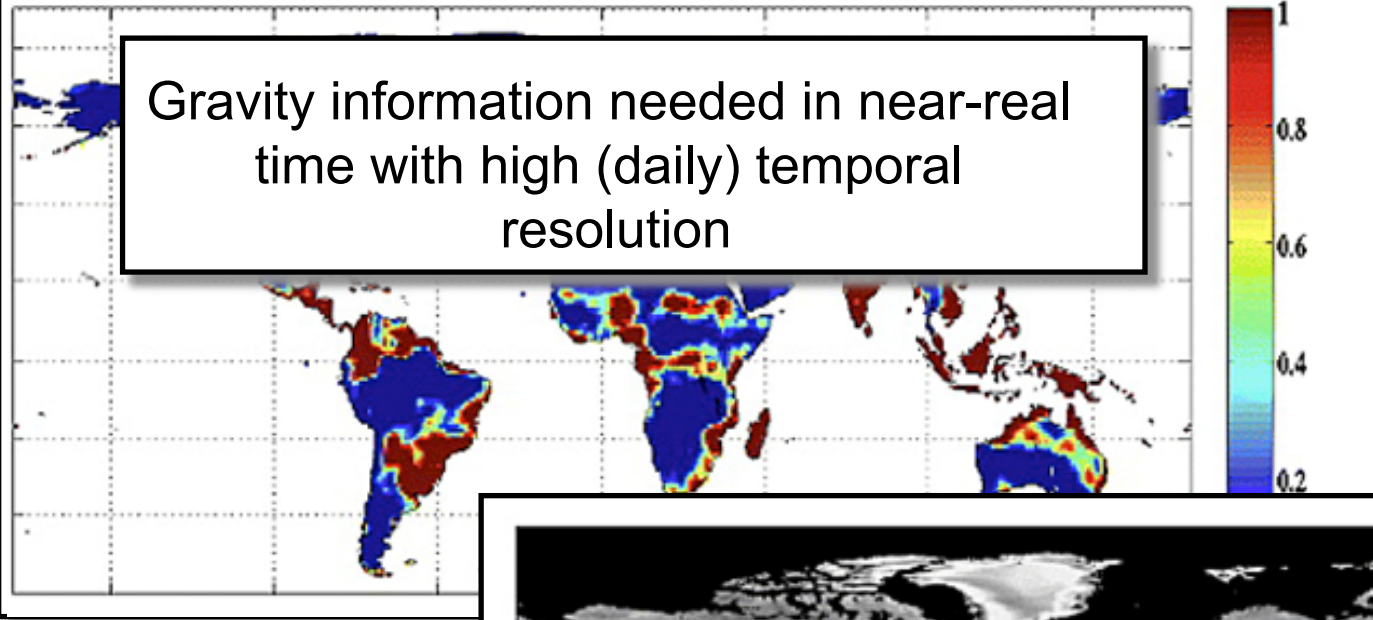
Danger of flooding



Flood indices for early
warning before flood
actually occurs

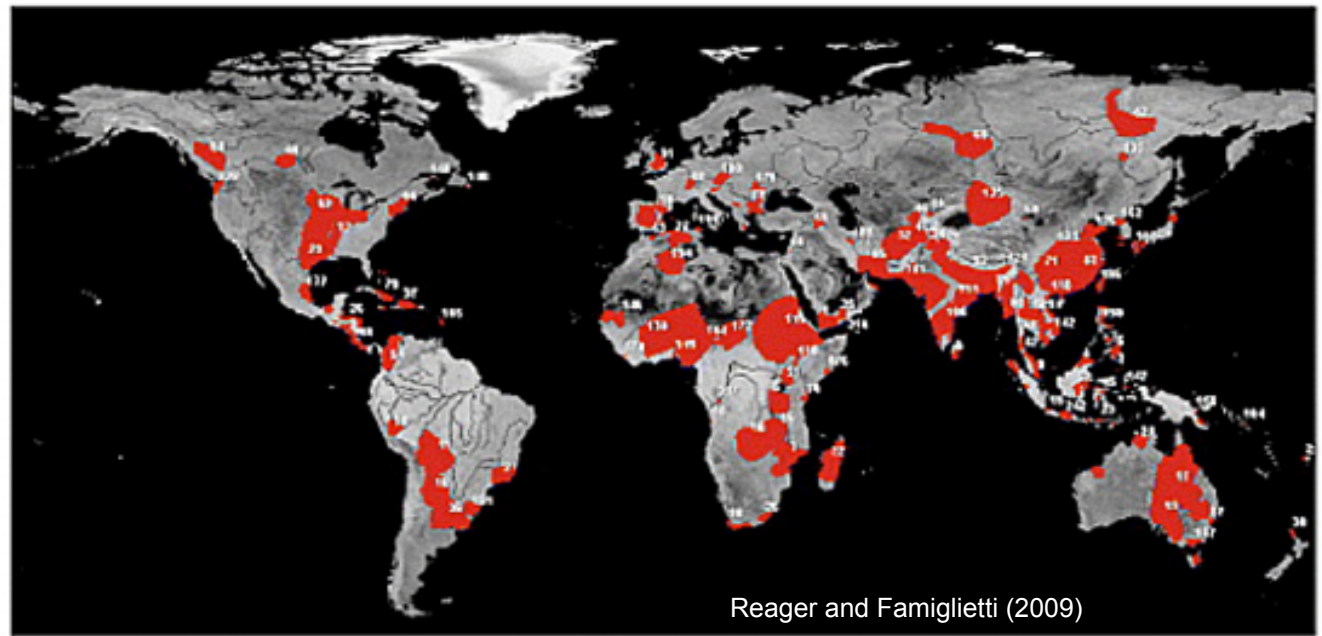
Gravity for early warning?

Gravity information needed in near-real time with high (daily) temporal resolution



GRACE-derived
flood index
(May 2007)

Floods that
actually happened
May 2007



Reager and Famiglietti (2009)

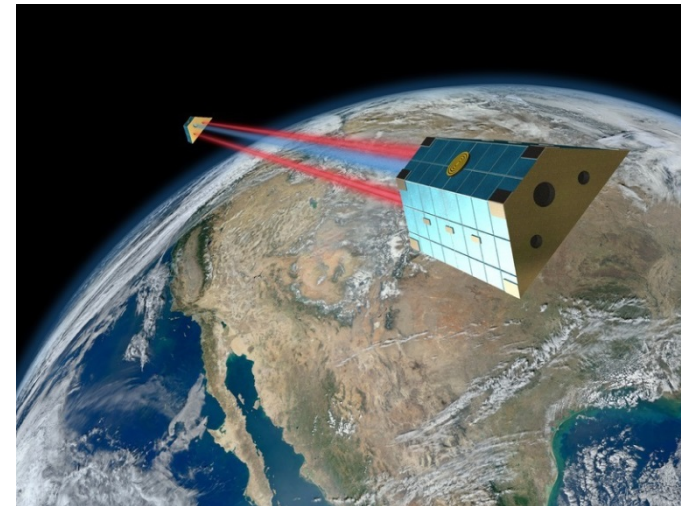
GRACE Follow-On

Salient Features

- Implemented under US-German partnership
- Tech-Demo Laser Ranging Interferometer is Class D
- Follow-on to original GRACE Mission launched 2002
- Launch: **December 2017 on SpaceX Falcon 9**
- Orbit: Near-circular Polar Orbit, 495 km altitude, 89° inclination

Science

- The GRACE-FO Mission will **continue and expand** upon the measurements initiated by the pathfinder GRACE Mission
- Will provide estimates of the **global high-resolution models of the Earth's gravity field for a period of up to five years** at a precision and temporal sampling equivalent to that achieved with GRACE.
- Will provide **QuickLook products for enhanced operational use** for water resource management
- The inter-satellite laser ranging interferometer will demonstrate satellite-to-satellite interferometry in low Earth orbit.



U.S. Drought Monitor

March 7, 2017
(Released Thursday, Mar. 9, 2017)
Valid 7 a.m. EST

Drought Impact Types:

- S = Short-Term, typically less than 6 months (e.g. agriculture, hydrology, L = Long-Term, typically greater than 6 months (e.g. hydrology, ecology)

Intensity:

- DO Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

Author:
Brian Fuchs
National Drought Mitigation Center

The Drought Monitor focuses on immediate conditions. Local conditions may vary. See accompanying text summary for detailed statements.

USDA
NOAA
NCEP

<http://droughtmonitor.unl.edu>

And more to come ...



Figure 1 consists of three panels. Panel (a) is a map of the Amazon basin with Basin 1 outlined in black and Basin 2 outlined in red. A color scale for precipitation is shown on the left. Panel (b) is a time series plot of precipitation (mm month⁻¹) for Basin 1 from 2003 to 2009. It shows four data series: TRMM 3B42 V7 (grey line), GPCC (blue line), APHRODITE (red line), and GRACE (green line). The y-axis ranges from 0 to 180 mm month⁻¹. Panel (c) is a line plot showing the fraction of GRACE precipitation for the same four datasets from February to December. The y-axis ranges from 0 to 1.5. The legend indicates: GPCC (blue), TRMM 3B42 (grey), TRMM 3B42 V7 (black), APHRODITE (red), and GPCC (green).

Land + Sea

Units Wm^{-2} at TOA

incoming solar TOA: 340 (340, 341)

solar reflected TOA: 100 (96, 100)

thermal outgoing TOA: 239 (236, 242)

solar absorbed atmosphere: 60 (74, 97)

atmospheric window: 239 (236, 242)

greenhouse gases: 239 (236, 242)

latent heat: 82 (70, 85)

solar down surface: 185 (179, 189)

solar surface: 25 (22, 28)

imbalance: 0.6 (0.2 - 1.0)

solar absorbed surface: 160 (154, 166)

evaporation: 82 (70, 85)

condensable heat: 21 (15, 25)

thermal up surface: 398 (384, 400)

thermal down surface: 342 (338, 348)



jpl.nasa.gov

BACK UP